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DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Electric Pulse Signalling System.

We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of STC House, 190 Strand, London, W.C.2, England, do hereby declare the invention, for which we
5 pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to pulse signalling
10 systems and more particularly to an improved correlation technique for use in pulse signalling systems.

Correlation techniques have been utilized in the past in signalling processing systems
15 employing signals in the form of a pulse or sequence of pulses. Such pulse signalling systems include, for example, radiant energy reflecting systems, such as radar, radio range finders, radio altimeters and the like; and
20 pulse communication systems, such as over-the-horizon systems employing various types of scatter techniques, satellite communication systems and the like. Correlation techniques when employed in radiant energy re-
25 flecting systems enhance the resolution of closely spaced reflecting surfaces and, in addition, particularly when wide pulse signal widths are employed, increase the average power transmitted. Correlation techniques
30 when employed in pulse communication systems result in increased signal-to-noise ratios without increase of transmitter power and minimized multiple path effects (fading).

According to prior art correlation techni-
35 ques the received signal is processed by obtaining the product of code elements of the received signal and code elements of a locally generated signal of the same waveform and period as the received signal and integrat-
40 ing the resultant product. The optimum output for such a correlation would be a single peak of high amplitude which has a width

[Price

substantially narrower than the pulse width of the received signal. Most correlation systems in use today do not produce the 45 desired optimum waveform, but rather provide an output whose waveform has spurious peaks in addition to the desired high amplitude peak. The presence of these spurious peaks is undesirable in that the resolving 50 power of radiant energy reflecting systems is reduced and the signal-to-noise ratio and minimization of multiple path effects of pulse communication systems is reduced to a level below the optimum value. 55

Therefore, an object of this invention to provide optimized pulse signalling systems utilizing correlation techniques which result in an impulse correlation function.

The term "impulse correlation function" 60 as employed herein refers to a waveform having a single high amplitude peak completely free from spurious peaks of lower amplitude elsewhere in the waveform.

Previously two correlation techniques have 65 been proposed that will result in an impulse correlation function. One of these techniques 10 described in British Specification No. 1,073,024 requires the generation of a first sequence of coded pulses, a replica of 70 this first sequence of coded pulses, and a second sequence of coded pulses. These two sequences of coded pulses are each separately correlated with the replica of the first sequence of coded pulses to produce from 75 each correlation separate correlated outputs which in turn are correlated to produce the impulse correlation function. The two sequences of coded pulses each have a distinctive code pattern so that when one of the 80 correlated outputs is a finite value the other correlated output is zero resulting in a zero output when these correlated outputs are correlated one with the other except when the

first and second sequences of coded pulses are in time coincidence with the replica of the first sequence of coded pulses. The second correlation technique to obtain an impulse correlation function requires the production of a sequence of coded pulses having a predetermined pattern·so that when this sequence of coded pulses and its replica are correlated a zero output will result at all times except when the sequence of coded pulses and its replica are in exact time coincidence.

The disadvantage of the first impulse correlation function technique above described is that of requiring the production of a second sequence of coded pulses to assure that when the first sequence of coded pulses and its replica are correlated and produce a finite output that the correlation between the second sequence of coded pulses and the replica of the first sequence of pulses is zero so as to produce a zero output in a third correlation process.

In the second impulse correlation function technique above described, the performance is optimum until it is desirable to employ an extremely long sequence of coded pulses to increase the average power transmitted. Then it becomes very tedious and requires a complex coding arrangement to generate the code that will provide the desired impulse correlation function and increased average transmitted power.

Therefore, another object of this invention is to provide pulse signalling systems incorporating impulse correlation function techniques which will maintain the coding circuitry relatively simple and will eliminate the necessity of generating a second sequence of coded pulses solely for purpose of forcing a zero output if the correlation between the first sequence of coded pulses and its replica does not result in a zero.

Still another object of this invention is to provide at least two multiplexed sequences of coded pulses to reduce the complexity of code generation and yet maintain the advantage of having a long sequence of coded pulses. .

According to this invention there is provided an electric pulse signalling system comprising a transmitter for transmitting a modulated signal, a means to generate at least first and second modulating signals which are applied in multiplex to modulate the transmitted signal and each of which is a sequence of coded pulses, the coding pattern of each sequence being different, a receiver which receives the transmitted modulated signal and derives from it replicas of the modulating sequences, and a correlation means to which are applied and correlated separately said derived replicas and delayable versions of said first and second modulating signals to produce an impulse output only at the time

of coincidence of the digits of said first and second sequences of coded pulses with said replicas of said first and second sequences of coded pulses and a zero output at all other times.

A feature of an embodiment of this invention is the provision of generating the first and second sequences of coded pulses in time sequence and disposing the replicas of the first and second sequences of coded pulses in the same time sequence.

A feature of a further embodiment of this invention is the provision of means to separate the first and second sequences of coded pulses which are generated in time coincidence on a frequency basis and, hence, separate the time coincident replicas of the first and second sequences of coded pulses on the same frequency basis.

The above-mentioned and other objects and features of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:—

Fig. 1 is a block diagram of a signalling system incorporating an impulse correlation function generator in accordance with the principles of this invention where the first and second sequences of coded pulses and their respective replicas are separated on a time basis;

Fig. 2 is a timing diagram useful in explaining the operation of Fig. 1;

Fig. 3 is a block diagram of a pulse signalling system incorporating an impulse correlation function generator in accordance with the principles of this invention where the first and second sequences of coded pulses and their respective replicas are separated on a frequency basis;

Fig. 4 is a timing diagram useful in explaining the operation of Fig. 3;

Fig. 5 is a bar graph illustrating the correlation function of a first sequence of coded pulses and its replica that may be employed in the systems of Figs. 1 and 3;

Fig. 6, 7, 8 and 9 are diagrams illustrating the correlation of the first sequence of coded pulses and its replica illustrated in Fig. 5 for various values of T;

Fig. 10 is a bar graph illustrating the correlation function of a second sequence of coded pulses and its replica that may be utilized in the systems of Figs. 1 and 3;

Figs. 11, 12, 13 and 14 are diagrams illustrating the correlation of the second sequence of coded pulses and its replica illustrated in Fig. 10 for various values of T;

Fig. 15 is a block diagram of one form of coder which may be utilized to generate the sequence of coded pulses in the systems of Figs. 1 and 3;

Figs. 16 and 17 are bar graphs of additional first and second sequences of coded

pulses which may be employed in the systems of Figs. 1 and 3;

Fig. 18 is a table illustrating the summation of the correlation products of the codes of Figs. 16 and 17 to produce the desired impulse correlation function output of the systems of Figs. 1 and 3; and

Fig. 19 is a block diagram of a coder that may be utilized to generate the codes of Figs. 16 and 17 for use in the systems of Figs. 1 and 3.

The description hereinbelow and the illustrations of the drawings is presented in connection with a radar system. However, it should be understood that the principles expounded hereinbelow can be applied to other systems; for instance, radio direction finders, radio altimeters, and radio communication systems used for over-the-horizon communication, satellite communication and the like employing pulse code modulation techniques and in particular orthogonal pulse code modulation techniques.

In Fig. 1, correlation means 1 receives first and second sequences of coded pulses from the outputs of modulators 2 and 3 and replicas of these first and second sequences of coded pulses from the output of receiver 4. The first and second sequences of coded pulses at the outputs of modulators 2 and 3 and their replicas at the output of receiver 4 are separated on a time basis and thus the system is a time multiplex system. The two sequences of coded pulses each have a different code pattern but are related to each other in such a way that when one sequence is correlated with its replica and the other sequence is correlated with its replica at least one resultant correlated output will have a value of zero in all time positions except at $T=0$, where T is the delay between each signal sequence and its replica as applied to the correlation means so that when these correlated outputs are correlated together the resultant output of correlation means 1 is a zero output for all time positions except when the first and second sequences of coded pulses are in time coincidence with their associated replicas.

More specifically, timing pulse generator 5 transmits its timing signal through normally conductive gate 6 to coder 7 to produce the first sequence of coded pulses to modulate the carrier signal produced by carrier source 8 in modulator 2. The timing pulse of generator 5 is also coupled to binary counter 9 to delay the triggering pulse from generator 5 a sufficient amount to achieve the desired time separation between the first and second sequences of coded pulses in the system of Fig. 1. When there is an output from counter 9, gate 6 is rendered nonconductive and coder 10 is triggered into operation to produce the second sequence of coded pulses to modulate the carrier from

source 8 in modulator 3. Gate 6 may take the form of an inhibit gate. The outputs from modulators 2 and 3 are coupled to linear adder 11 to add these two signals linearly for modulating the radio transmitter 12 for radiation from antenna 13. The reflected or echo signals resulting from intercepting a reflecting object is received at antenna 14 and coupled to receiver 4 wherein the time spaced first and second sequences of coded pulses are recovered by two stages of demodulation for application to correlation means 1.

The first sequence of coded pulses at the output of modulator 2 is coupled through variable delay device 15 to one input of multiplier 16 and the second sequence of coded pulses at the output of modulator 3 is coupled through variable device 15 to one input of multiplier 17. The other input of multiplier 16 is coupled to the output of receiver 4 and the other input of multiplier 17 is coupled to the output of receiver 4. Due to the time relationship between the first and second sequences of coded pulses at the output of modulators 2 and 3 and the corresponding time relationship between the replica of the first sequence of coded pulses and the replica of the second sequence of coded pulses at the output of receiver 4, multiplier 16 acts to correlate only the first sequence of coded pulses with its replica and multiplier 17 acts to correlate only the second sequence of pulses and its replica. Thus, multiplier 16 does not perform a correlation between the first sequence of coded pulses and the replica of the second sequence of coded pulses, nor does the multiplier 17 perform a correlation between the second sequence of coded pulses and the replica of the first sequence of coded pulses. The output of multiplier 16 is coupled to integrator 18 which will integrate and store the resultant correlation over a large number of pulses containing the first sequence of coded pulses. Integrator 19 performs the same function with respect to multiplier 17 and the second sequence of coded pulses. This operation of integrators 18 and 19 places the correlated output therefrom on the same time basis.

As hereinabove mentioned, the codes of the coded sequences are each different one from the other but related thereto so that if integrator 18 at one time position other than $T=0$ provides an output having a finite value, the output of integrator 19 is zero. The reverse condition is also true. Thus, when the outputs of integrators 18 and 19 are coupled to multiplier 20 the resultant output of multiplier 20 will be zero and will be integrated in integrator 21. Multiplier 20 will always produce a zero output regardless of which integrator 18 or 19 has a zero output except when T equals zero, where T

equals the relative time displacement between the sequences of coded pulses and their replicas. When T equals zero, the first sequence of coded pulses is in time coincidence with its replica and the second sequence of the coded pulses is in time coincidence with its replica.

Fig. 2 illustrates a timing diagram which is useful in understanding the operation of Fig. 1. Curve A illustrates the output of modulator 2 which is the first sequence of coded pulses. Curve B illustrates the output of modulator 3 which is the second sequence of coded pulses. It should be noted that in both Curves A and B the sequence of coded pulses are contained within one wide pulse 22 and may contain therein a number of bits depending upon the length of each of the first and second sequence of coded pulses. Curve C illustrates the resultant multiplexed output of adder 11 wherein the sequences of coded pulses of the output of modulators 2 and 3 are time interleaved. The receiver 4 produces at its output the waveform illustrated in Curve D. It will be observed that there is a time difference between the waveforms of Curves C and D which is proportional to twice the distance to the target intercepted by the transmitted coded sequences. Curves E and F illustrate the output of delay device 15 at T=n, where n equals a finite value of relative time displacement between the sequences of coded pulses and their replicas. Comparing Curves D and E, it is seen that the first bit of the replica of the first sequence of coded pulses at the output of receiver 4 is coincident with the last bit of the first sequence of coded pulses at the output of delay device 15. This same relationship is present when comparing Curves D and F. Any value of T including that illustrated in Curves E and F and up to but not including that illustrated in Curves G and H will produce a zero output from correlation means 1. However, when the output of delay device 15 is related to Curve D as illustrated in Curves G and H, that is, when the first sequence of coded pulses and its replica and the second sequence of coded pulses and its replica are in time coincidence there will be an output of finite value from integrators 18 and 19 and, thus, an output of finite value from multiplier 20 and an impulse will be present at the output of correlation means 1. Therefore, the desired impulse correlation function is generated.

Fig. 3 illustrates another multiplex arrangement incorporating the improved correlation techniques in accordance with the principles of the invention. Correlation means 1a receives from modulator 2 the first sequence of coded pulses as illustrated in curve A, Fig. 4 and from modulator 3 the second sequence of coded pulses as illustrated in Curve B, Fig. 4. In addition correlation means 1a receives the replica of the first and second sequences of coded pulses from the output of receiver 4.

Components common to Figs. 1 and 3 have been given the same reference characters. The primary difference between the arrangement of Fig. 1 and Fig. 3 is that the coders 7 and 10 are simultaneously triggered by the output of generator 5 and couple their coded pulses to modulators 2 and 3 to produce the sequence of coded pulses contained in pulses 23 of Curves A and B, Fig. 4. A source 24 is coupled to modulator 2 to provide a carrier signal having a frequency f_1 and a source 25 is coupled to modulator 3 to provide a carrier signal having a frequency f_2. Thus, the outputs of modulators 2 and 3 are applied to linear adder 11 simultaneously but separated from each other on a frequency basis resulting in the pulse output as illustrated in curve C, Fig. 4. This frequency multiplexed signal is then applied through amplifier 12 to antenna 13 for transmission to a distant target. The reflection from the distant target is received by antenna 14 and the replicas of the first and second sequence of coded pulses are provided at the output of receiver 4 for coupling to correlation means 1a.

The output of receiver 4 is illustrated in Curve D, Fig. 4 and is displaced in time from Curve C, Fig. 4 due to the distance the transmitted pulse had to travel to the target and back to the receiver.

The output from modulator 2 is coupled through variable delay device 15 to multiplier 16 while the output from modulator 3 is coupled through variable delay device 15 to multiplier 17. The output of receiver 4 is coupled to both multipliers 16 and 17 when switches 26, 27, 28 and 29 are in the position illustrated. The correlation between the first sequence of coded pulses and the replica thereof takes place in multiplier 16 and the correlation between the second sequence of coded pulses and the replica thereof takes place in multiplier 17. The integrators 18 and 19 coupled to the outputs of multipliers 16 and 17, respectively, produce output signals including zero. In addition integrators 18 and 19 which are in effect low pass filters have their frequency characteristic adjusted to pass only the correlation of the first sequence of coded pulses and the replica thereof at frequency f_1 through integrator 18 and to pass the correlation of the second sequence of coded pulses and the replica thereof at frequency f_2 through integrator 19. The output of integrators 18 and 19 are coupled to multiplier 20 and, thence, to integrator 21 to produce an output from the correlation means 1a.

As in the case of the arrangement of Fig. 1, the two sequences of coded pulses each have a different code pattern so that if at T

not equal to zero an output other than zero is produced at the output of integrator 18 there is an output from integrator 19 equal to zero so that when these two values are correlated in multiplier 20 there results a zero output from correlation means 1a. In a like manner, at T not equal to zero, when there is an output from integrator 19 of a given magnitude the output from integrator 18 is zero so that multiplier 20 produces no output for correlation means 1a. However, at T equals zero, when both integrators 18 and 19 produce a finite output there is an output from multiplier 20 and integrator 21 and, hence, an impulse at the output of correlation means 1a. Thus, correlation means 1a provides the desired impulse correlation function.

Rather than just relying upon the passband of integrators 18 and 19 to separate the two frequency multiplexed sequences of coded pulses, switches 26 through 29 can be moved to their other position and apply the output from receiver 4 through the bandpass filters 30 and 31. In this arrangement, bandpass filter 30 would pass the replica of the second sequence of coded pulses having a center frequency f_2 while bandpass filter 31 will pass the replica of the first sequence of coded pulses having a center frequency f_1. When this arrangement is employed, the replicas of the first and second sequences of coded pulses are separated from each other prior to application to multipliers 16 and 17 to accomplish the desired correlation between the first and second sequence of pulses and their replicas.

Curves E and F, Fig. 4 illustrate the output of delay device 15 for both the first and second sequence of coded pulses, respectively with the last bit of these sequences of coded pulses being in coincidence with the first bit of the replicas thereof at the output of receiver 4. When Curves D and E and Curves D and F are correlated in multipliers 16 and 17, respectively, a zero output will result from correlation means 1a, since the correlation product of at least one of these multipliers is zero. Curves G and H, Fig. 4 illustrate the output of delay device 15 at a time T equals zero for both the first and second sequence of coded pulses. At this time there will be an output from both integrators 18 and 19, since the first and second sequence of coded pulses and their replicas are in time coincidence resulting in an output from multiplier 20 and integrator 21 and, hence, an impulse at the output of correlation means 1a.

The systems of Figs. 1 and 3 will produce the desired impulse correlation function if the following conditions are met:

$$\int S_1 (t + T) \times [S_1 (t) + S_2 (t)] = 0$$

for all values of T except when T=0 and when

$$\int S_2 (t + T) \times [S_1 (t) + S_2 (t)] = 0$$

Figures 5 and 10 illustrate, respectively, two different sequences of coded pulses which enable both the systems of Figs. 1 and 3 to meet the above conditions and produce the desired impulse correlation function. The code is set forth in both Figs. 5 and 10 as the coordinate values of the bar graph of these figures with the code bits thereof being indicated by the values +0, −0, +1 or −1 which correspond to different phases of a reference signal as follows:

$$
\begin{aligned}
+0 &= +90° \\
-0 &= -90° \\
+1 &= 0° \\
-1 &= 180°
\end{aligned}
$$

The value in ( ) next to the phase indication of a code bit in Fig. 10 represents the magnitude of this particular bit of the code. Where there is no value in ( ) in Figs. 5 and 10, it is to be understood that the magnitude of the code bit is unity.

The correlation of the first sequence of coded pulses and its replica for different values of T from T=9 to T=0 is illustrated in Fig. 5 by the diagonal rows containing the same circled number. The correlation of the second sequence of coded pulse and its replica for different values of T from T=9 to T=0 is illustrated in Fig. 10 by the diagonal rows containing the same circled number. By summing the quantities in each of the diagonal rows for each value for T, it is possible to determine the correlation function of each of the sequence of coded pulses of both Figs. 5 and 10. Taking a particular value of T and summing the corresponding diagonal rows of each graph of Figs. 5 and 10, it is possible to determine the resultant output of multipliers 16 and 17, Figs. 1 and 3 at the selected value of T.

The correlation product indicated in each square of the bar graphs of Figs. 5 and 10, is obtained in accordance with the following logic equations which determine the sense or zeros only and not the magnitude of the bit:

$$
\begin{aligned}
\pm 1 &\times \pm 1 &= +1 \\
\pm 0 &\times \pm 1 &= 0 \\
\pm 0 &\times \pm 0 &= +1 \\
\pm 0 &\times \mp 0 &= -1 \\
\pm 1 &\times \mp 1 &= -1 \\
\mp 0 &\times \pm 1 &= 0
\end{aligned}
$$

The magnitude of the bits is the product of the magnitude of the correlated bits times the result of the appropriate one of the above logic equations.

Figs. 6 through 9 illustrate the relationship between the first sequence of coded pulses and its replica of Fig. 5 for the indicated values of T while Figs. 11 through 14 illus-
5 trate the relationship between the second sequence of coded pulses and its replica of Fig. 10 for the same values of T. Both these groups of Figures are going to be used to illustrate how the correlation means 1 or
10 1a of Figs. 1 and 3 cooperate to the end of achieving an impulse correlation function in accordance with the principles of this invention.

In Fig. 6, T equals 9 bits and the code of
15 Fig. 5 is shown in its relationship with its replica resulting in a sum equal to zero. This would be the output of integrator 18 in both Figs. 1 and 3, when this value is multiplied in multiplier 20, Figs. 1 and 3, with whatever
20 value is present at the output of integrator 19, the resultant output of multiplier 20 would be zero. However, Fig. 11 illustrates the relationship between the second sequence of coded pulses of Fig. 10 and its replica for
25 T equals 9 bits which results in a sum equal to zero.

Consider now Fig. 7 where T equals 4 bits. The output of delay device 15, namely S_1 (t+T) is shown in relationship with its
30 replica at the output of receiver, namely S_1 (t). Taking the products, according to the above logic and algebraically adding it is found that the sum is equal to -2. This finite value would appear at the output of
35 integrator 18, Figs. 1 and 3. To assure that no output occurs from correlation means 1 or 1a, the second sequence of coded pulses or in other words the code of Fig. 10, has a predetermined pattern to produce a sum
40 equal to zero for T equal to 4 bits. Fig. 12 illustrates the relationship between S_2 (t+T) and S_2 (t), Rec., the resultant correlation products and their sum which equals zero. This will be the output of integrator 19, Fig. 1 and
45 3. The zero at the output of integrator 19 even though there is a -2 output from integrator 18 results in a zero at the output of multiplier 20 and, hence, no output from correlation means 1 or 1a.
50 Fig. 8 shows the relationship between the first sequence of coded pulses of Fig. 5 and its replica when T equals 2 bits. Fig. 13 shows the same thing for the code of Fig. 10. Fig. 8 illustrates that there is a +2 out-
55 put of integrator 18, Fig. 1 and 3 and Fig. 13 illustrates that there is a zero output from integrator 19, Fig. 1 and 3 due to the summation of the correlation products obtained in multipliers 16 and 17. Since there
60 is zero output from integrator 19, multiplier 20 will also produce a zero output resulting in no output from correlation means 1 or 1a.

Figs. 9 and 14 illustrate time coincidence
65 between the code of Fig. 5 and its replica

and time coincidence between the code of Fig. 10 and its replica. The output of integrator 18, Fig. 1 and 3 is +10 units according to Fig. 9 and the output of integrator 19, Figs. 1 and 3 is +10½ units according to
70 Fig. 14 and, hence, multiplier 20 produces an impulse of 10×10½ units at the output of correlation means 1 or 1a.

The foregoing illustrates how the code of Fig. 10 cooperates with the code of Fig. 5 on
75 a multiplex basis, either time or frequency multiplex, to assure an impulse correlation function at the output of correlation means 1 or 1a. It will be appreciated that at all values of T at least one of the sequences of
80 coded pulses produces a zero and thus there is no output from correlation means 1 or 1a except at T equals zero when both sequences of coded pulses produce finite output level. It is this cooperation of the multiplexed se-
85 quences of coded pulses that reduces the tedious and complex job of producing a long sequence of coded pulses which when correlated with a replica thereof produces a zero output at all times except at T equals
90 zero.

Fig. 15 illustrates one form of coders 7 and 10, Figs. 1 and 3. With switches 32, 33, and 34 in the position illustrated, coder 7,
95 Figs. 1 and 3 is provided to generate the code of Fig. 5. When switches 32, 33 and 34 are moved to their other position there is provided coder 10, Figs. 1 and 3 to generate the code of Fig. 10. It should be noted
100 that switches 32, 33 and 34 switch in different amplitude of a selected phase of the output signal of oscillator 35 to produce the desired amplitude for the particular phase of signal coupled to linear adder 36. A pulse
105 from generator 5 triggers oscillator 35 into operation and produces an oscillatory output having a reference phase of 0°. This phase of signal is applied to amplifiers 37, 38 and 39. It will be appreciated that amplifier 37
110 produces unity amplitude for the oscillatory output of oscillator 35 at a 0° phase shift while amplifiers 38 and 39 produce, respectively, half of unity and three times unity amplitude for the same 0° phase shift to pro-
115 duce the indicated outputs for bits two and four of the code illustrated in Fig. 10. The output of amplifiers 37, 38 and 39 are coupled to gates 40, 41 and 42, respectively.

The output from oscillator 35 is also
120 coupled to a 90° phase shifter 43 which shifts the reference phase of the output of oscillator 35 by a 90° phase shift prior to coupling to amplifiers 44 and 45. It will be appreciated that the output of amplifier 44
125 is unity amplitude and is coupled to gate 46 while the output of amplifier 45 is one-half of unity amplitude required to generate the ninth bit of the code of Fig. 10, and is coupled to gate 47.

The output of oscillator 35 is also coupled 130

to phase shifter 48 and 49 to provide a 180° phase shift and a 270° phase shift, respectively, of the output of oscillator 35. Since both codes of Figs. 5 and 10 require only a unity magnitude for the −1 and −0 phase conditions of the code there is provided only one amplifier 50 producing unity amplitude coupled to shifter 48 and only one amplifier 51 producing unity amplitude coupled to phase shifter 49. The outputs of amplifiers 50 and 51 are coupled to gates 52 and 53, respectively.

At a time delayed from the start of oscillator 35, as provided by the delay line 54, there are produced timing signals on the ten output taps of delay line 54 which will in sequence trigger or gate the proper gates 40, 46, 52 and 53 to produce the code of Fig. 5 with the switches 32, 33 and 34 in the position indicated. For instance, the output from the first tap of delay 54 is coupled to gate 53 to produce a −0 phase condition which is the condition for the first bit of the code of Fig. 5. The output from the second tap of delay line 54 is coupled to gate 40 to produce the +1 phase condition for the second bit of the code of Fig. 5. Continuing on down the output taps of delay line 54 and following their connections to the appropriate ones of gates 40, 46, 52 and 53 it can be readily ascertained how the code of Fig. 5 is generated without a further lengthy discussion.

To generate the code of Fig. 10 all that is necessary is to change the position of switches 32, 33, and 34 to their other position and thereby connect gates 41, 42 and 47 to the appropriate time position tap of delay 54 in place of gates 40 and 46 as illustrated. As before the connections to the delay line taps can be traced to the appropriate one of the gates 40, 41, 42, 46, 47, 52 and 53 to determine the manner of generating the code of Fig. 10 and remove the necessity of a lengthy discussion of how each bit of the code is generated.

Figs. 16 and 17 illustrate two other codes that may be employed in the arrangements of Figs. 1 and 3 to produce the desired impulse correlation function at the output of correlation means 1 or 1a. The bar graph of Fig. 16 illustrates the correlation products of the first sequence of coded pulses wherein the numerals in the circles indicate the particular value of T. Fig. 17 is a bar graph illustrating the second sequence of coded pulses wherein the numbers in the circle again represent the particular value of T. In both Figs. 16 and 17, as was described in connection with Figs. 5 and 10, it is possible to take a diagonal row having the same numeral in the circle and obtain the summation of the correlation products of the codes illustrated in Figs. 16 and 17 for the various values of T.

The result of summing the diagonal rows of Figs. 16 and 17 is illustrated in Fig. 18 and clearly demonstrates how at least one of the codes in Figs. 16 and 17 is equal to zero at all values of T except T=0. Thus, in Figs. 1 and 3, when multiplier 20 operates upon the output of integrators 18 and 19 at various values of T there results at the output of correlation means 1 all zeros except at T=0 when an impulse of +20 is produced.

It will be recognized that the codes of Figs. 16 and 17 are simple binary codes and may be generated as illustrated in Fig. 19. Oscillator 55 is triggered on by the output of timing pulse generator 5 and is coupled directly to amplifier 56 without any phase shift and is provided with an amplitude of unity for coupling to gate 57. The output of oscillator 55 is also coupled to phase shifter 58 which shifts the phase of the oscillatory output of oscillator 55 by 180°. This is applied to amplifier 59 and, hence, to gate 60 with unity amplitude. "1" has been designated as zero phase and is present at output of gate 57 while "0" has been designated as 180° phase and is present at the output of gate 60. Code bits from gates 57 and 60 are provided under control of the output of delay line 61. With switches 62 and 63 in the position illustrated there will be generated the code of Fig. 16 with an output from gate 60 at the first time interval, an output from gate 57 at the second time interval, an output from gate 60 at the third time interval, and an output from gate 60 at the fourth time interval.

When it is desired to generate the code of Fig. 17, switches 62 and 63 are moved to their other position so that at the first time interval there is an output from gate 60, at the second time interval there is an output from gate 57, at the third time interval there is an output from gate 57, at the fourth time interval there is an output from gate 60, and at the fifth time interval there is an output from gate 60. The output from gates 57 and 60 are coupled to linear adder 64 to produce the code selected from the codes illustrated in Fig. 16 and 17.
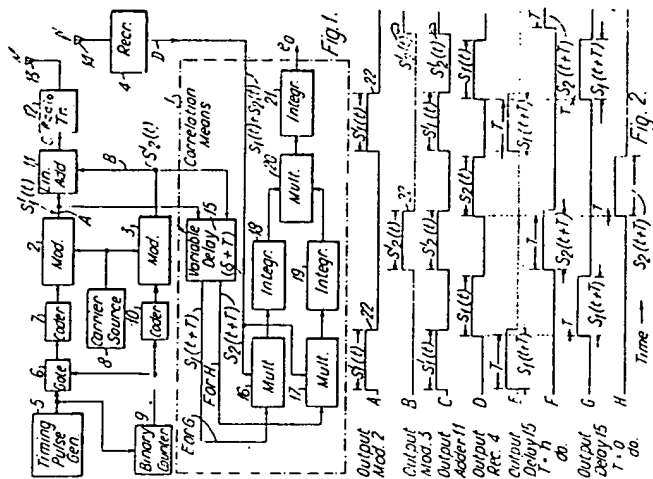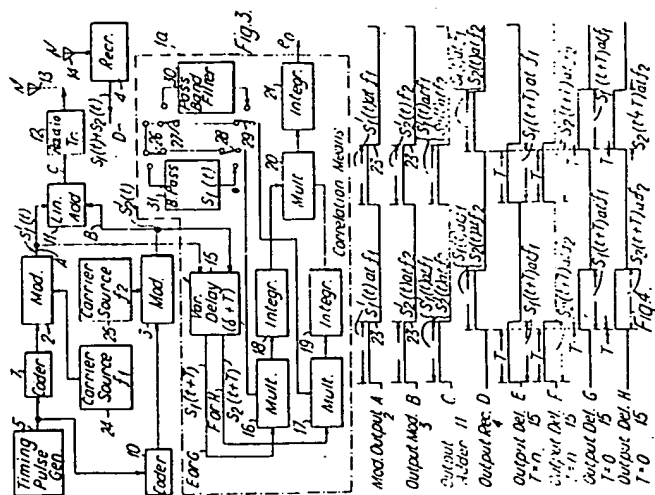
The above description has been directed to two codes in multiplex. However, this is not to be considered as a limitation to the invention, since an impulse correlation function can be produced using the same techniques with N codes. All that is required is that when N codes are correlated at least one of the N codes be equal to zero for all values of T except for T equals zero.
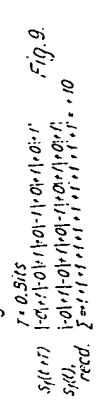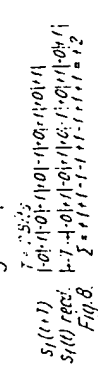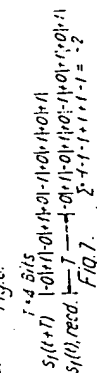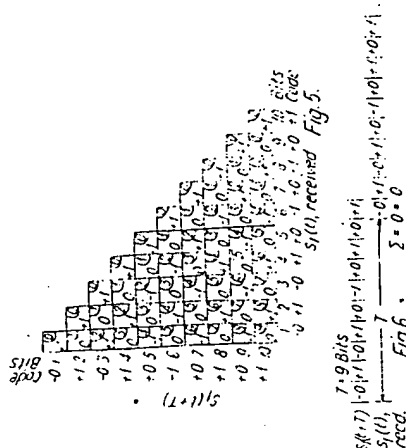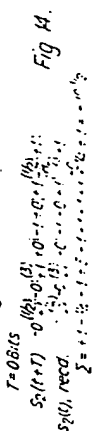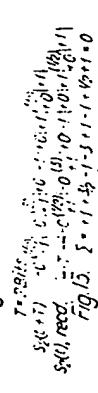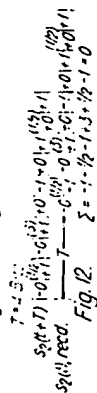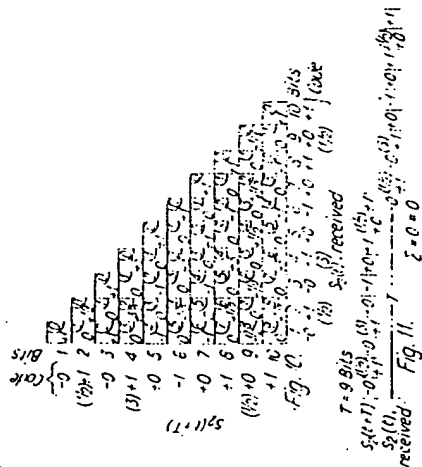
WHAT WE CLAIM IS:—

1. An electric pulse signalling system comprising a transmitter for transmitting a modulated signal, a means to generate at least first and second modulating signals which are applied in multiplex to modulate the transmitted signal and each of which is

a sequence of coded pulses, the coding pattern of each sequence being different, a receiver which receives the transmitted modulated signal and derives from it replicas of the modulating sequences, and a correlation means to which are applied and correlated separately said derived replicas and delayable versions of said first and second modulating signals to produce an impulse output only at the time of coincidence of the digits of said first and second sequences of coded pulses with said replicas of said first and second sequences of coded pulses and a zero output at all other times.

2. A system according to claim 1, wherein said generating means includes
means to dispose said first and second sequences of coded pulses in time sequence so that said replicas of said first and second sequences of coded pulses are also disposed in time sequence.

3. A system according to claim 2, wherein said correlation means includes
a first correlation channel responsive to said first sequence of coded pulses and said replica of said first sequence of coded pulses to provide therefrom a first correlated output,
at least a second correlation channel responsive to said second sequence of coded pulses and said replica of said second sequence of coded pulses to provide therefrom a second correlated output,
at least one of said first and second correlated outputs being equal to zero at said all other times and both of said first and second correlated outputs being an impulse output at said time of coincidence, and
first means coupled to said first and second correlation channels for correlating said first and second correlated outputs to produce an impulse output at said time of coincidence and a zero output at said all other times.

4. A system according to claim 3, wherein said correlation means further includes
a delay means coupled to an input of said first and second correlation channels and said generating means to vary the time of arrival of said first and second sequences of coded pulses at said input of said first and second correlation channels.

5. A system according to claim 3, wherein said first correlation channel, said second correlation channel and said first means each include a serially connected multiplier and an integrator.

6. A system according to claim 1, wherein said generating means includes
means to modulate said first and second sequences of coded pulses in time coincidence but on to carrier waves of different frequencies.

7. A system according to claim 6, wherein said correlation means includes
a first correlation channel responsive to said first sequence of coded pulses and said replica of said first sequence of coded pulses to provide therefrom a first correlated output,
at least a second correlation channel responsive to said second sequence of coded pulses and said replica of said second sequence of coded pulses to provide therefrom a second correlated output,
at least one of said first and second correlated outputs being equal to zero at said all other times and both of said first and second correlated outputs being an impulse output at said time of coincidence, and
first means coupled to said first and second correlation channels for correlating said first and second correlated outputs to produce an impulse output at said time of coincidence and a zero output at said all other times.

8. A system according to claim 7, wherein said correlation means further includes
a delay means coupled to an input of said first and second correlation channels and said generating means to vary the time of arrival of said first and second sequences of coded pulses at said input of said first and second correlation channels.

9. A system according to claim 7, wherein said correlation means further includes
filter means to separate said replicas of said first and second sequences of coded pulses from each other and couple said separated replicas of said first and second sequences of coded pulses to the appropriate one of said first and second correlation channels.

10. A system according to claim 7, wherein said first correlation channel, said second correlation channel and said first means each include a serially connected multiplier and an integrator.

P. G. RUFFHEAD,
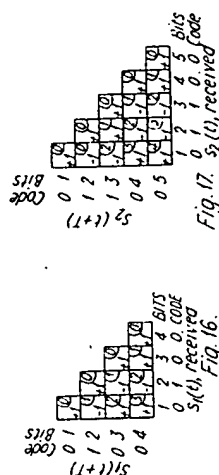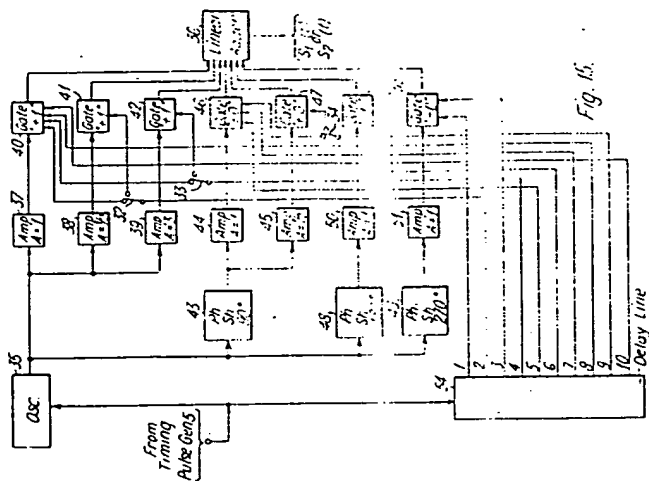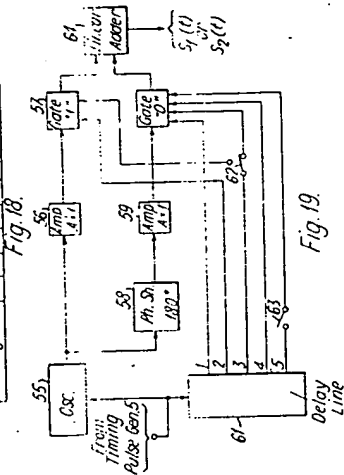Chartered Patent Agent,
For the Applicants.

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Sheets 1 & 2

Fig.1.

Fig.2.

Fig.3

Fig.4.

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Sheets 3 & 4

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 14.

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Sheets 5 & 6

Fig. 15.

Fig. 16.

Fig. 17.

Fig. 18.

Fig. 19.